Polytechnical University of catalonia

Bachelor's degree thesis

Study of the Lockheed SR-71 structure and reproduction of a 1:20 scale model

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Abstract

The Lockheed SR-71 was a strategic reconnaissance aircraft developed during the Cold War in the 60s, flown by NASA and the USAF. It is one of the most significant vehicles produced in the history of aviation, and a pioneer in the field of aerospace engineering, especially for its stealth technology and hypersonic capability. Due to its astonishing performance, even in today's standards (Mach 3+), and shape, the also called Blackbird is admired by many enthusiasts all over the world. This study has the objective to deepen in the airplane structure design, specifically for the SR-71. Then, through 3D CAD software, plans will be created to assemble a 1:20 scale model of the airframe.

Chapter 1

Introduction

1.1 Aim

Reproduction of the Lockheed SR-71 Blackbird structure on a 1:20 scale model, after having created its 3D CAD plans through a detailed study. This project will provide knowledge of how a plane is developed and built, and more specifically for this airplane, its internal ribs and components will be properly shown.

1.2 Scope

- Detailed research and study of the aircraft
- Study of the plans
- 3D CAD design of the structure
- Sketch of the 1:20 scale plans in order to assemble a model
- Using of the plans to create the pieces of the structure with wood
- Assembling of the model
- Analysis of the obtained results
- Development of a report

1.3 Requirements

- A scale model shall be constructed
- This Final Degree Thesis has a dedication time of approximately 300 hours.
- In order to do the project, CAD programs will be used, specifically *Solidworks*.
- In order to cut the wood, an external specialist in the area will be contacted.
- All documents will be written in English.

1.4 Justification

The Lockheed SR-71 is one of the most significant aircrafts produced in history. Although having been developed between the late 1950s and early 60s, with a lot less technology than today's standards, it still holds records, such as crossing the Atlantic Sea (from New York to London) in less than two hours. Another important aspect to mention is its stratospheric ceiling of service, of 26,000 m.

Figure 1.1: *The Lockheed SR-71 "Blackbird"*[4]

In order to create such an outstanding machine, a number of earlier programmes had to be conducted. Also, it is important to note that not only Lockheed worked on the project. Also, the Central Intelligence Agency and US Air Force came into play, which gives an idea of the complexity of the plane.

The so-recognisable lines that the SR-71 structure make up, designed by Clarence L. "Kelly" Johnson, are still admired by many enthusiasts all over the world.

The structure, the most important feature to take into account in this project had many particularities. Not only its unusual form, but also the materials used – the majority of it was made from titanium. This was done in order to properly function under extremely conditions.

All these facts have helped to decide to embark on the project of creating a model of the structure of this airplane, in order to better understand the process of building a vehicle of this characteristics and specifically this one, that is very appealing.

Through the development of the work, it is expected that many aspects of the construction of an aircraft will be better understood. Not only the physical building of the structures and frames, but also the computer design using CAD programs. In addition, a proper planning has to be performed in order to arrive at the desirable final result.

Chapter 2

State of the art

As an introduction, it is going to be explained the background of the SR-71, in order to get a better perspective of the era on which it was designed and produced.

The creation of the SR-71 started in the middle of Cold War, at the late 50s and early 60s. Even though, it has to be mentioned that this aircraft, as many others used in military, had to be designed from previous programmes and technology.

One of the most important requirements that were designated to the Central Intelligence Agency and the USAF was to identify and collect information of enemy territory, for example images and confidential data.

Before the birth of the SR-71 family, the Lockheed U-2 was the reconnaissance aircraft used by the US. On 4 July 1956, this airplane achieved for the first time to complete an operational overflight on the Soviet Union. With this 8 hours and 45 minutes flight,[1] it became evident the enormous potential of this kind of reconnaissance operations, because it achieved to obtain high-resolution imagery with a clarity never seen before.

But this achievement had an apparent problem, that was the upcoming Soviet anti-aircraft technologies. Although the Lockheed U-2 was capable to fly at 21,000 m,[2] these new instruments designed by the soviets could detect the missions developed by the American plane. This aspect could negatively affect the success of the missions and the probability of survival. Then, it became obvious that a solution was needed, thus a new project.

The aeronautical engineer Clarence L. 'Kelly' Johnson, that also designed the U-2, president of 'Skunk Works', Lockheed's highly classified manufacturing facility, began working on the project of creating a successor. The first objective, as it has been said, was to develop an aircraft that was very difficult to detect by radars. This was actually the first time that 'stealth technology', as it is called today, was considered in an aircraft's design.

After research was performed, the first thing that the plane needed to have was a reduced Radar Cross Section (RCS).[9] In order to achieve this, some aspects of the vehicle were modified:

- Shape: flattened, with tapered sides
- Special radar-absorbing materials (RAM)
- Fuel additives, from Cesium: reduction of exhaust plumes visible to radars

Figure 2.1: Lockheed U-2[16]

Although these technologies were incorporated, the stealth capability of the plane that was to be designed relied mostly on the ability to fly extremely fast and high.

2.1 Development

As it has been said, the SR-71 was created inside the division Lockheed Skunk Works, led by Clarence L. 'Kelly' Johnson.

The first prototype that was created, the Arrow 1 was followed by the Archangel I, dating around October 1957. This was actually the first aircraft that eventually led to the A-12 (the SR-71 predecessor). Then an Archangel II was designed, with the particularity of mounting two turbo jets at each side of the mid span and a pair of ramjets at each wingtip.

It has to be mentioned that Lockheed wasn't the only company trying to find a replacement for the U-2. Convair also came into play with the development of FISH. It was a parasite designed to be carried by the bomber B-58B, produced by the same constructor. The concept was cancelled, and a redesign appeared, the Kingfish. This prototype had very similar performance to the A-12, and used the same engines.

These two companies competed to obtain financing from CIA's Contingency Reserve Fund for the developing of either two aircrafts. Lockheed finally received the notification of winning this competition. Then between 1960 and 1962, several tests were conducted with a model of the A-12, to evaluate the design at speeds up to Mach 3.5.

In 1964, two more planes of the family were created. These were the M-21 and the SR-71. The first one had the peculiarity of being able to carry and launch a drone, designated as D-21, also used as a reconnaissance vehicle.

2.2 The Blackbird family

Here, the different models of the Blackbird family (name given to describe the black high-emissivity paint covering the surface of the aircrafts) will be described and differentiated:

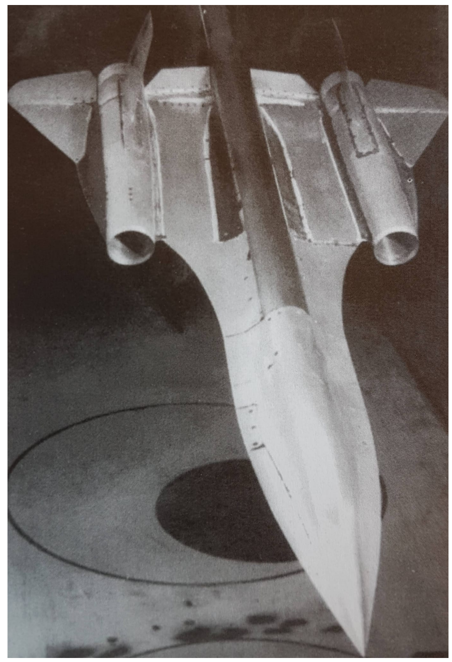


Figure 2.2: Scale model of an A-12 during tunnel tests[1]

A-12

As it has been explained, the A-12 was the original plane designed by Skunk Works. The major difference with its successors is the fact that its crew was only 1 pilot. It was only used for 29 total missions.

There were also two-seat trainer versions, but only 2 airplanes were built.

YF-12

The YF-12 was a prototype interceptor aircraft. Then, it was equipped with weapons, concretely 3 air-to-air missiles. Its crew was composed of the pilot and a fire control officer.

Its most distinctive aspect is that its nose didn't have the characteristic chines that the other Blackbirds did. Also, the lower fins.

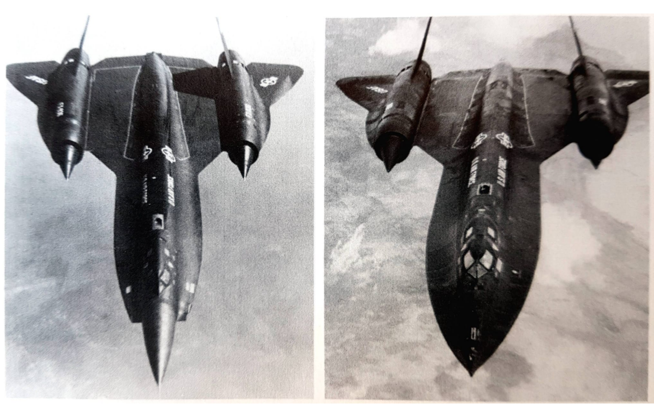


Figure 2.3: *Comparison between a YF-12 (left) and a SR-71A (right)*[2]

M-21

The M-21 was a two seat variant of the A-12. It
was designed specifically to carry a Lockheed D-21 drone. This unmanned aircraft carried a high resolution camera. It was launched from the back of the M-21 and it would self-destruct after flying over the target and ejecting the camera module.

Figure 2.4: *M-21 carrying a D-21 drone*[18]

SR-71

Designed to be a successor of the YF-12 an act as a reconnaissance platform, it incorporated again the distinctive nose with its chines. The SR-71 had to variants:

- SR-71A: standard version, and a crew of 2: pilot and reconnaissance systems officer (RSO).
- SR-71B: trainer version, and a crew of 2: pilot and instructor.

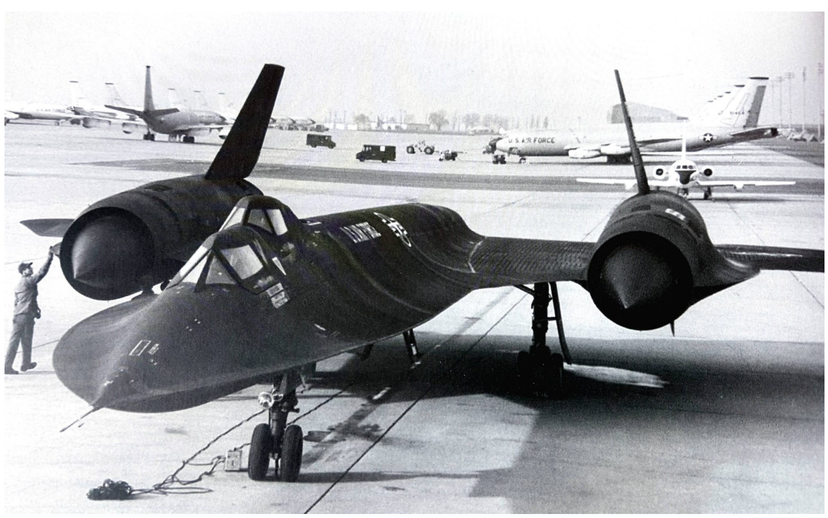


Figure 2.5: *Lockheed SR-71B, trainer version featuring 2 pilot seats. (Note the second elevated windshield)*[1]

Chapter 3

Features

In order to build the SR-71, many challenging aspects had to be faced. These were mostly due to the high-speed flying. This caused, among other things, that some parts of the surface of the aircraft had to resist temperatures up to 560 ° C.[7]

In order to perform at these temperatures, only two materials were appropriate: Titanium and steel. But this last, was extremely heavy. This aspect is crucial in aerospace engineering. In addition, Titanium had double the strength than steel, and also had a density much lower. Using these innovative materials had also many challenges. For example, it had to be very careful with the contamination found in paints, adhesive tapes, plastics, etc; so the workers constructing the vehicle had to be very careful using compatible materials.

3.0.1 Materials

The majority of the SR-71 and its variants were made of titanium alloys (93%).[2] Another important aspect to mention was the Material Removal Rate (MRR) of the Titanium alloys, that were only a 5% of the MRR that Aluminium would have, so in order to increase this, technicians had to develop other machinery to properly work on these alloys.

In some parts, like in leading and trailing edge, vertical stabilizers, chines and inlet spikes, in order to reduce radar signature, laminates were used. In particular: phenyl silane, silicone asbestos and fibreglass. It is known that plastics and fibreglass are less reflective and even transparent to radar, unlike metal which is strongly reflective.

Highlight the nickname Blackbird, to describe the black paint that covered the entire surface of the aircraft. It was used to increase the emission of internal heat (it had high-emissivity) and also acted as camouflage in night flights.

The plane was mostly made of titanium. It is a lustrous transition metal. Its most similar material in terms of strength is stainless steel, but half the density. In fact, titanium has the highest strength-to-density ratio of any metallic element.

In some parts of the structure, it was also used stainless steel, and could properly withstand the high temperatures caused by the number of Mach achieved by the plane.

Other areas, such as the engine nacelle exhaust ejector had to resist even higher temperatures. There, two types of nickel alloys were used.

In order to reduce the airplane's Radar Cross Section (RCS), plastic parts were used, mostly on the outer or peripheral sections of it, like the edges, chines, vertical stabilizers, etc.

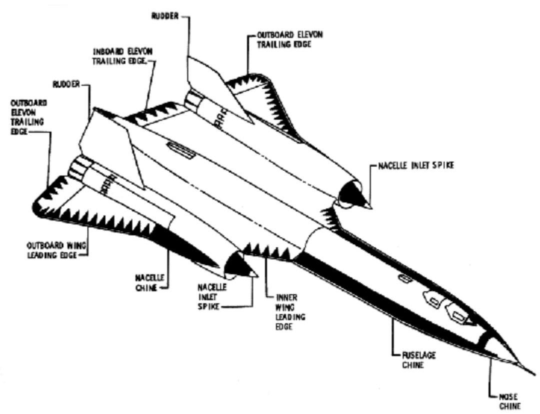


Figure 3.1: *Peripheral components of the SR-71*[17]

Chapter 4

Parts and structure

The SR-71 was a pioneer in achieving such high speed and flying altitude, and in consequence, the fact to withstand extreme temperatures and conditions. In addition, in order to provide the crew with a comfortable, who were frequently on 10 hours or more missions, the aircraft had to provide life-support systems for the pilots, and features to sustain life in emergency scenarios.

Image 4.1 shows an schematic of the Lockheed SR-71's structure and systems, with a legend for each part made by Mike Badrocke. This cutaway view has been the most used reference in order to reproduce the structure of the plane and to create the model, as will be explained later, in *CAD design*. Highlight the difference of cockpits between the SR-71A and SR-71B. The last incorporates as can be seen in Image 4.1 the second raised cockpit for the instructor.

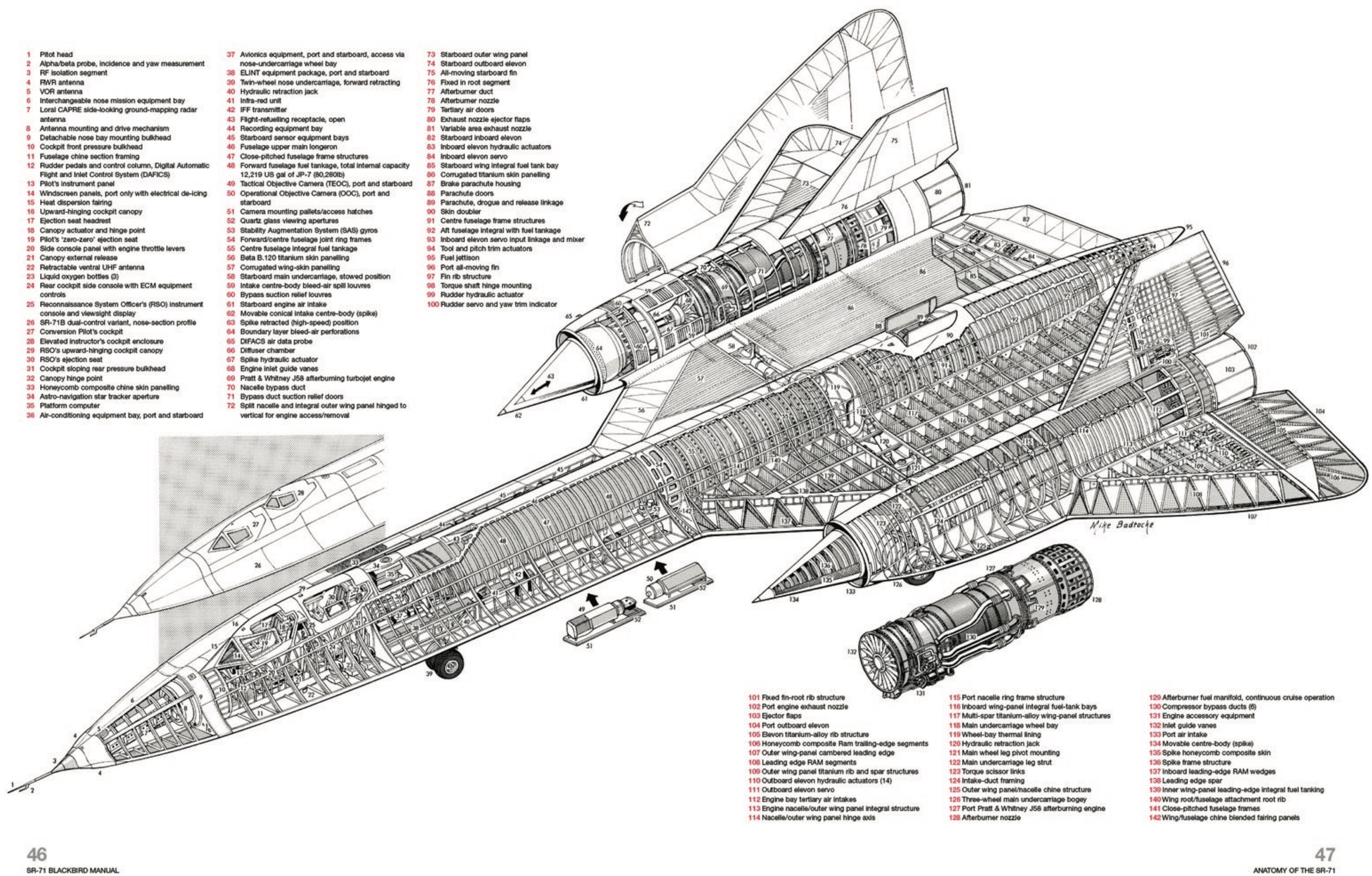
4.0.1 Dimensions

The model that is worked on this project, the Lockheed SR-71A has a length of 32.7m and a wingspan of 16.9m. The corresponding area for the wing is 149 m^2. Its loaded weight was between 61,290 and 63,560kg.

The Blackbird had 2 fins, separated each other 6.9m, and they were canted inwards at an angle of 15^o. The rudders were installed in them, so they had both the purposes of stabilizers and control surface areas.

The majority of the aircraft incorporated the mentioned chines, that provided a considerable amount of the total lift that the SR-71 generated. Also, they were used to incorporate equipment needed for the missions.

Figure 4.1: Mike Badrocke's Lockheed SR-71 structure cutaway[1]



4.0.2 Structure

The extraordinary performance of the Blackbird was highly attributable to its airframe, featuring some innovative designs on its semi-monocoque fuselage structure.[7] The framework was created using fuselage rings and longerons. The chines were formed by non-metallic composite honeycomb panels secured to titanium ribs. The structure for the chines was attached to the fuselage, as fairings. These generated up to 20%[2] of the total lift generated by the aircraft. Additionally, they provided a favorable effect on other aerodynamic aspects such as the trim drag (created by control surfaces). Also, the vortices generated at this parts of the airplane improved directional stability, affected by the angle of the attack.

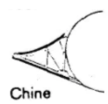


Figure 4.2: *Diagram of a chine attached to a frame*[9]

4.0.3 Components

The airframe of the SR-71 is composed by 3 very differentiated parts: Nose section, forward fuselage and aft fuselage. This can be seen in Image 4.3

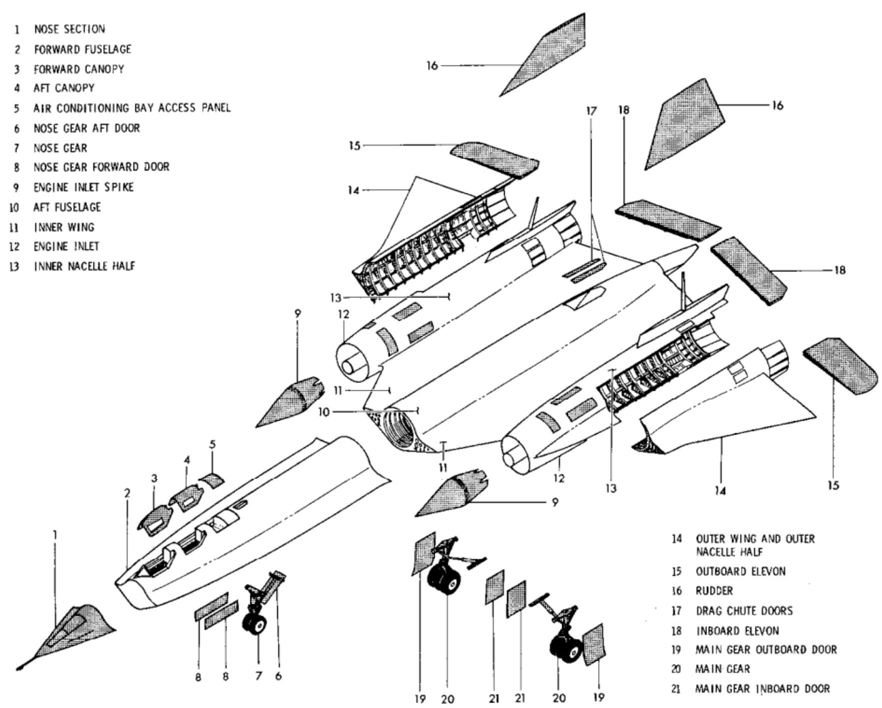


Figure 4.3: *Principal SR-71 airframe components*[10]

Nose section

Its nose section was detachable and it incorporated a pitot mast, and it was used as a radar station. When it comes to the structure, it incorporates frames united using longerons, to create a semi-monocoque structure.

Forward fuselage

The forward fuselage was formed by the mentioned semi-monocoque structure featuring rings and attached to it chines. It incorporated the cockpit (monocoque structure), providing space for both the pilot, at the front, and the Reconnaissance Systems Officer's cockpit at the back. Then, the pilot had access to the controls and instruments necessary to fly the aircraft, while the RSO was in charge of communication and navigation controls. It also had space for the nose landing gear (located beneath the RSO's cockpit), electrical and air conditioning bays, radio and an aerial refuelling door.

Aft fuselage

The aft fuselage was attached to the inner and outer wing, the nacelles and the different flight control surfaces: elevon (both ailerons and elevators), that were distributed in two parts (inboard and outboard); and the rudders. It must be mentioned that the outer wing was attached to a nacelle half as can be seen in Image 4.3

The wings were constructed using a multi-spar configuration, that is using 3 or more spars, with stressed skin panels that all together formed box beams. Wing beams extended through the fuselage, ending at the nacelle structures at each side of the aircraft. The nacelles supported the rudders and contained the two J58 Pratt and Whitney engines.

The inner wing contained the main landing gear, that with the nose landing gear composed a tricycle type. It was electrically controlled and hydraulically actuated. Each main landing gear featured three tubeless tyres (silver color) that reflected heat, and they were inflated with nitrogen.

Both front and aft fuselage and the majority of the inner wings contained the fuel tanks. The fuel system of the Lockheed SR-71 were composed by the mentioned tanks, valves, manifolds, pumps and others. Not only did it provide fuel for the engines, but it also had a very important mission to cool other systems. All the tanks combined had a capacity of 36,447 kg of JP-7. JP-7 is the turbine fuel, low volatility developed for the USAF to use firstly in the turbojet engines used by the Blackbird family, the Pratt and Whitney J58. Because of the high temperatures achieved on the surface of the aircraft, a fuel with high thermal stability was needed.

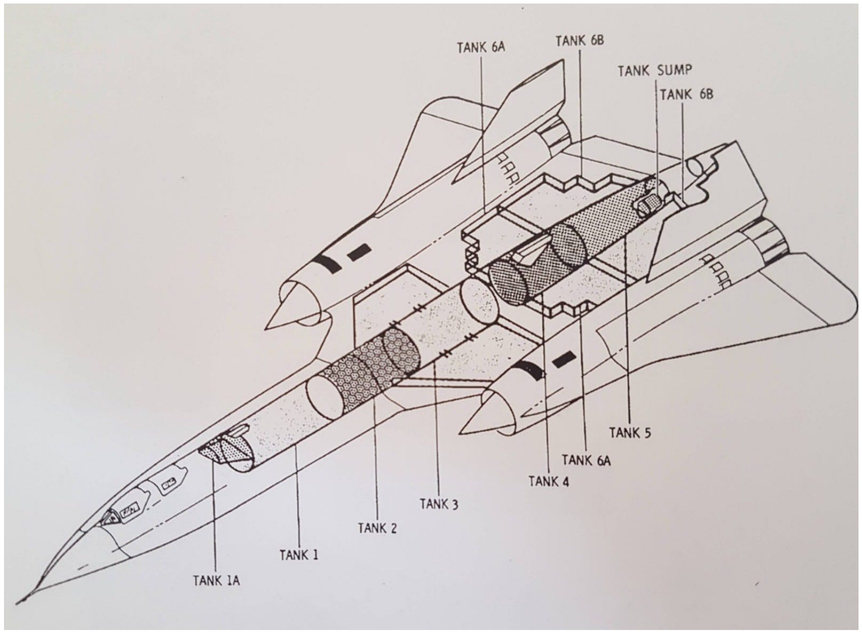


Figure 4.4: *Connected fuel tanks of the SR-71* [12]

4.0.4 Temperatures

Since various parts of the aircraft were at different temperatures, many aspects had to be considered for the design. For example, there was a corrugation on the upper and lower wing surfaces in order to permit expansion and contraction during flight. Actually, because of the dilatation caused by heat, the fuselage frames only achieved a proper alignment in flight, when the temperature was high enough to expand. In other words, when the aircraft was on the ground, several parts of the structure were fit loosely.

At the highest speed that the plane could achieve (Mach 3.2), the temperatures for some parts of the airplane were:

Part of the aircraft	Temperature (°F)	Temperature (°C)
Nose	573	301
Front cockpit windshield	622	328
Rudder leading edge	577	303
Engine nacelle (front)	587	308
Engine nacelle (middle)	1050	566
Engine nacelle (aft)	1200	649

Table 4.1: Maximum temperatures experienced by different parts of the Lockheed SR-71[8]

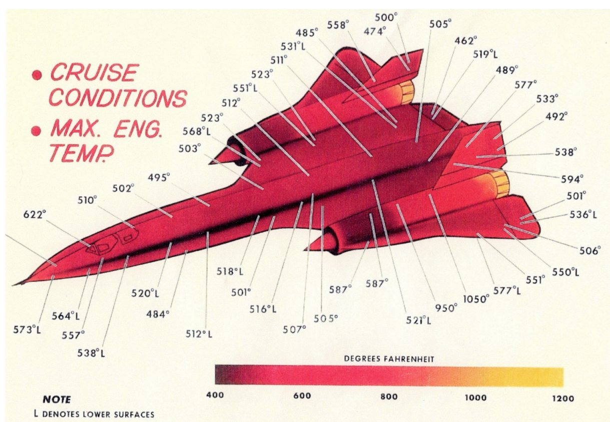


Figure 4.5: *Temperatures on the surfaces of the Blackbird*[9]

Chapter 5

CAD design

The essential part of this project, and what occupies most of the time of it is getting the plans of the different parts of the structure of the aircraft. Then, as has been said, a CAD design of the structure. It has been decided to use Solidworks, one of the most known 2D and 3D CAD software.

In order to get the plans to build a model of the structure, and besides all the research done of the theoretical side of the aircraft, that is the precedent Sections, another research has needed to be done. This includes:

- Drawings: cutaways of the SR-71
- Photographs
- Plans
- Other information

One of the most important references for this project is the cutaway created by Michael Badrocke of the Lockheed SR-71 (can be seen in *Parts and structure* Chapter, Figure 4.1). It provides a view of the insides of the aircraft. That is its structure, the internal components, instruments, etc; all properly indicated in order to get the information for a person that is recreating the aircraft.

Also, it has been important the study of photographs of the aircraft. Being a secret military aircraft, though, it is more difficult to access to certain documentation. The most important photos that have been tried to find are those made on a construction phase. In some of them, that will be shown later, some parts of the structure can be seen, and can be compared with the drawing cutaways and plans in order to select the correct data.

In addition, other plans that provide all views of the plane are essential to get the data of measures and disposition of all components of the aircraft. Also, considering the peculiar shape of it, all these kind of views are very important to capture and represent a more realistic model of the plane.

Finally, it has been very important the reading of all the possible information that could be gathered from official websites, portals, enthusiasts blogs, etc. There, written explanations can be found so that the parts that can't be properly shown by all the other mentioned sources can provide the necessary information. That is:

- Type of structure (semi-monocoque, monocoque)
- The shape of some parts of the structure
- How the structure is assembled
- Materials
- Dimensions
- Disposition

5.0.1 Monocoque and semi-monocoque structure

The Lockheed SR-71 combines two of the most used types of structures in aircraft. Monocoque and semi-monocoque structure. In order to better understand the structure of the airplane of this project, it has been made a study of this two structural techniques.

First, the monocoque, as the name indicates, this structure is basically a single shell. The stresses applied on it are endured by a thin membrane, also called skin. This contrasts with the other types of structure, that use a collection of beams and longerons in order to assemble the aircraft.

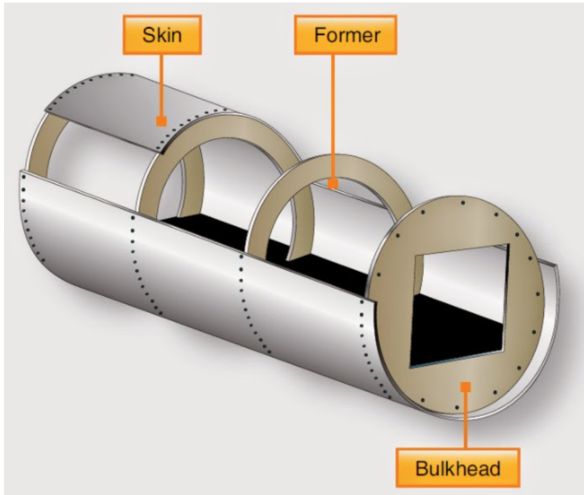


Figure 5.1: *Monocoque structure*[20]

It incorporates formers or frame assemblies that are united to the skin. This structural features are usually concentrated in parts of the aircraft were other sub-assemblies are attached, such as wings or other systems. Then, as can be seen, the skin must both stand the primary stresses and keep the fuselage rigid. Although this structure is stiff - in bending,[19] it tends to have a considerable structural instability. The structural phenomena that the monocoque usually encounters are buckling and crippling. The best way to see this is by taking the example of an aluminum can, that's actually the most simple quotidian object that uses this technology.

In order to solve this instability, a number of support structures are added. These are the mentioned longerons. These have the principal objective of giving the airframe a proper behavior in bending that the monocoque has. This, then, is a semi-monocoque structure, and is the most used one in aeronautics. It is a good compromise between the low weight that the monocoque provides (and a very crucial parameter in airplane design), and good structural strength.

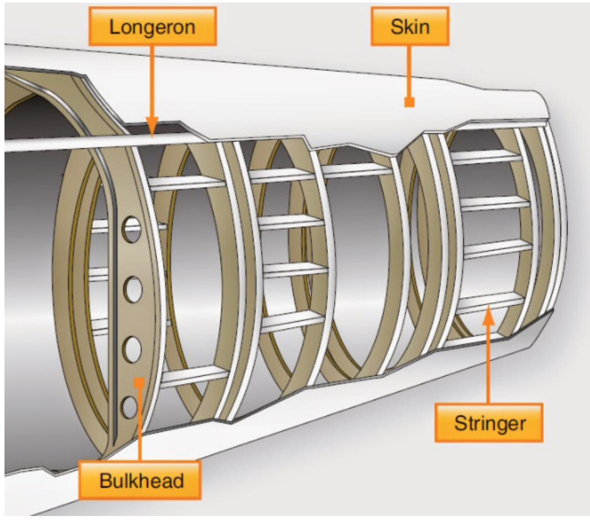


Figure 5.2: *Semi-monocoque*[20]

In semi-monocoque airframes, there's often added the stringers. These are some support pieces, between formers or frame assemblies, as can be seen in Image 5.2.

It must be mentioned that there's another type of airframe that has been present in the history of aviation. That is the trussed structure. It's a rigid framework, normally composed by bars and spars or rods. This type of structure, though, it is not generally used in today's airplane standards.

Figure 5.3: *A Blériot XI, a 1908 airplane, showing its trussed structure*[23]

Then, as a general point of view, and having seen these structures, the Blackbird uses a monocoque/semi-monocoque structure for the fuselage (both front and aft). The wings, that are attached to the aft fuselage feature ribs and spars to form them, and covered with a corrugated skin.

The skin in the SR-71 was a very important part of the structure. Most of the skin was made of Titanium and was stressed in order to help to support the longerons and ribs to create the airframe. This, as has been seen, is characteristic of a monocoque. The peculiar and well-known chines of the airplane were covered by silicone asbestos and didn't actually have a significant contribution to the assembly, in contrast with the Titanium skin.

This chapter will be partitioned between the different parts that compose the aircraft, seen at the Chapter of Parts and Structure. It will be a process, from front to aft, seeing the components and how they are assembled into the total unit. Logically, how they have been implemented into the CAD software will be regarded too.

5.1 Nose section

The front part of the Lockheed SR-71 is detachable and incorporates the antennas (VOR and RWR) and the systems required to make them work properly. Also, the pitot mast, to measure and calculate the air velocity.

As can be seen in Figure 5.4, it is partitioned in two parts. In the front, the antennas and attached to them the pitot mast. At the back, there's a structure of frames and longerons, that is connected to other parts of the front of the plane. It is important to mention, that this part, as many others as has been said, the skin participates importantly in the structure. These frames leave space for the Loral CAPRE side-looking ground-mapping radar antenna. This radar, used with others, was used for navigation and illuminate ground targets that were to be recorded.

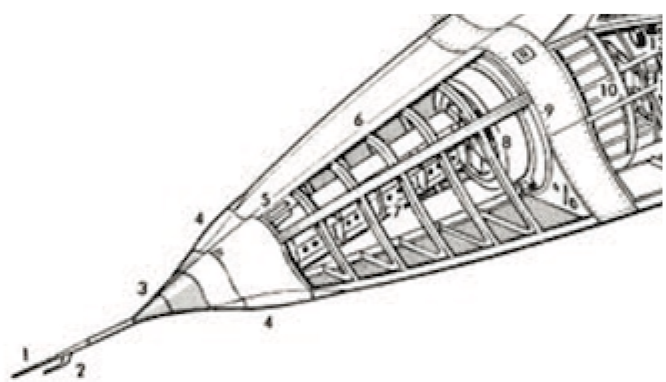


Figure 5.4: *Nose section of the SR-71*[1]

The most frontal part has not been considered as part of the structure, then hasn't been covered in the CAD.

The shape of it is not regular. It has been created with plans' aid. These are shown below, in Figures 5.5 and 5.6. The first reference offers a better look to the exact shape, while the other reference has been used to take measures of the disposition of elements.

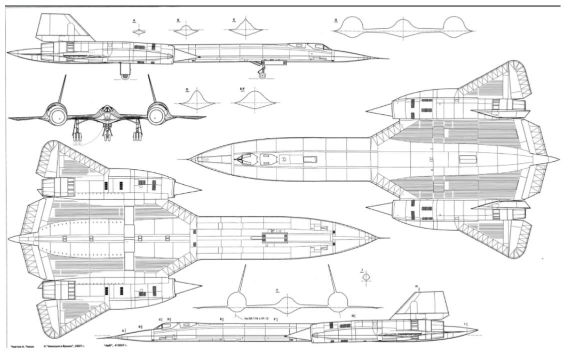


Figure 5.5: *Plans of the Lockheed SR-71, with the shape of some parts of the airframe*[21]

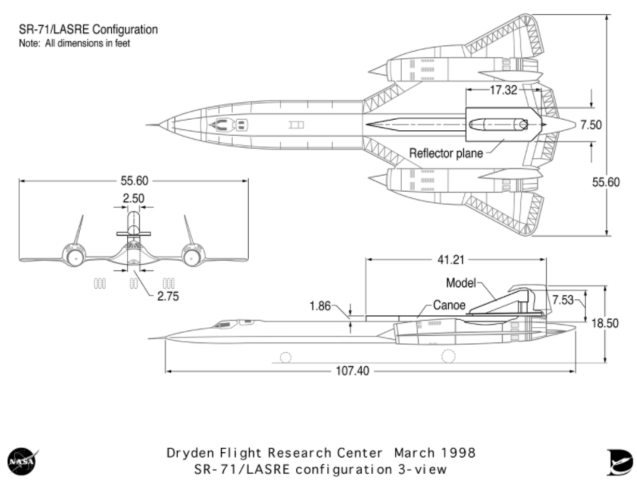


Figure 5.6: *NASA plans of the Lockheed SR-71, with its principal dimensions*[12]

The conclusion is that, to form the shape, it is required a central circumference, and tangent to them a tear shape, that will be repeated all over the plane to form the chines.

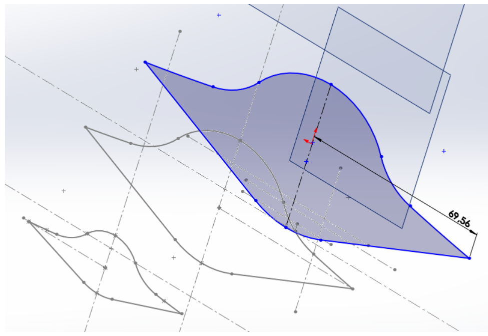


Figure 5.7: *Operation to form the nose frames*

Then, it has been created the section that corresponds to the final part of the nose, and a line of tendency that unites both frontal and back. Considering afterwards the number of frames required, and the space available, it has been calculated the distance between them. All this, obviously, taking into account the 1:20 scale of the model to be created.

It has been decided, considering the thickness of the materials available in the market, and the plans, that the frames are 3mm and the longerons, in this case, 2mm. The perforation made inside each frame follows the same pattern as the outer. It has been used the Operation in *Solidworks* of *Offset entities*.

In order to adjust the longerons to the frames, some orifices have been done to these last ones, with a width of the thickness of the longerons to later be adjusted when the model has to be assembled.

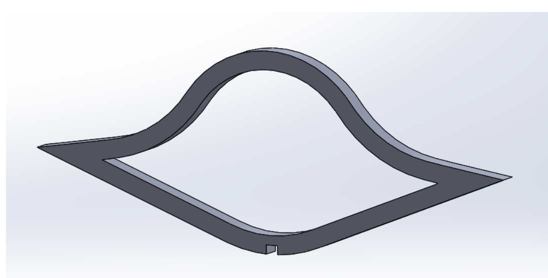


Figure 5.8: *Close look at a frame of the nose section*

The last frame is supposed to be solid, or with no central hole. That generates a better support for the rest of the airframe.

Then, the number of frames of this section is:

- 6 holed frames
- 1 solid frame

5.2 Forward fuselage

The forward fuselage is composed by the cabin (both pilot and RSO) and a regular part-circular fuselage, that is used, among other systems and elements to incorporate the front tank of JP-7, that fuels the J58 engines.

Here, again, similarly to the Nose Section, the principal shape of the frames is circular, with the chines attached to them. Nevertheless, the cabin has a very irregular shape, and this circular central form is altered with a superior parabolic-like shape.

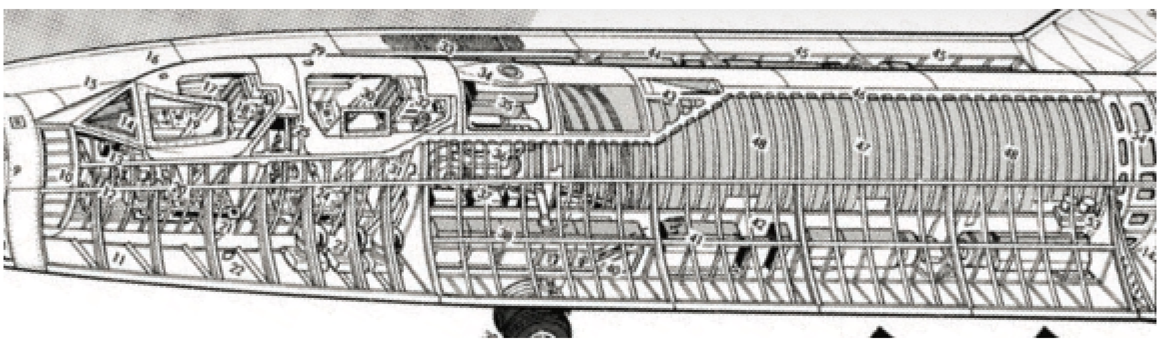


Figure 5.9: *Front fuselage of the SR-71*[1]

In reality, some parts of the cabin section are movable, that, is, so that the crew can enter and exit the airplane. But, for this, project, it has been regarded as a fixed part in order to obtain a better assembly and avoid an aspect that may be too difficult to represent. The inner part of each frame, for this section, must have the space to fit a person, and it has been taking into account, always considering the scale. This cabin section and its movable entry doors is shown in Image 5.10. As it can be seen, the shape is not circular and ends in a pointy edge- from the windshield, and it gets more and more rounder as it gets to the more regular part that is located at the back of the front fuselage.

Figure 5.10: *Cabin of the Blackbird, with the doors opened*[22]

Taking a look to Figure 5.9, it can be seen that between every frame (that has attached chines), there's a circular ring to make the structure stronger. It is attached to the longeron.

As it gets to the back, as it has been said earlier, the shape gets more circular on the center of the frame until it's completely a circumference. This pattern of frame and ring frame is repeated along the fuselage. The ribs that unite them all are located at the upper and lower part of the fuselage, in the symmetry line. Also, there's two ribs at each side of the SR-71, one that helps making the chine structure stronger and another that is used to make the central part of the fuselage more rigid. They can be seen in Figure 5.9. The chines rib has a pattern of rectangular holes along its length. These two structural elements leave a space between them, and was used to carry some systems units such as the infrared, IFF (Identification, Friend or Foe) transmitter, recording equipment and various sensors.

So, the sections from the cockpit have a more irregular shape. In order to create them, it has been consulted some drawings that give a more detailed view on the shape of them.[21] The information gathered has been contrasted with historical photos of the SR-71 and the official plans given by Lockheed Martin, obtained from the Book[1]

To design the part where the front fuselage starts transforming into more regular frames, it has been used the tool *Loft*, so that it can be obtained a smoother change of the profile. The lines of tendency have been created (using lateral and top views of the airplane). Then, knowing the space between each rib, they are created with an intersection of the planes for the pieces and the loft. Then, it has been used the operation *Boundary Boss Base* so that the piece has a regular thickness (how they will constructed later after having been cut).

The tendence of a frame with no chines attached to it between those that have them is repeated along the front fuselage.

Part	Number of frames with chines	Number of frames	Thickness
Cabin	8	8	3 mm
Not regular	6	6	2 mm
Regular	16	15	2 mm

Table 5.1: Number of frames in the front fuselage

For the ribs in the regular part of the fuselage, logically, it has been needed to use an Operation to repeat entities. In this case, *Linear Pattern*. Image 5.11 shows the chined frames used for this part. As can be seen, they have the openings that should be used to carry all the equipment mentioned before. It's circular on the center and it has a support on each side to link up with the chines' rib.

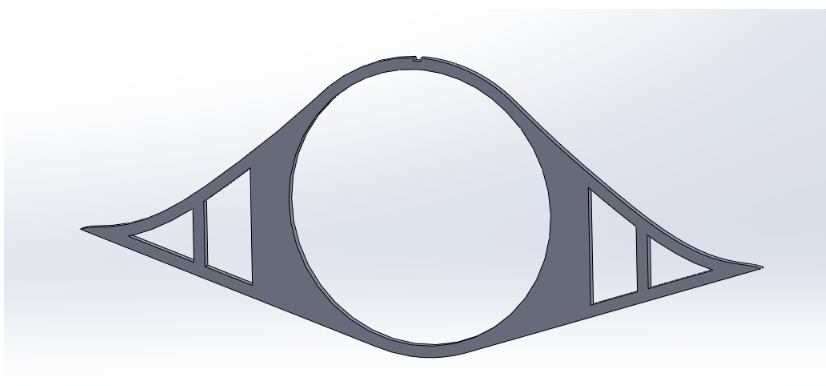


Figure 5.11: *Regular chined frames*

5.3 Aft

The aft part of the Lockheed SR-71 (Image 5.12) is the most complex one of the aircraft, then the difficulty linked to the creation of the CAD and the construction of a model is also significantly higher. This section regards not only the fuselage, but also the wings, control surfaces and the nacelles (that carry the engines).

It must be emphasized that the objective has been to recreate the aircraft in the most realistic way possible. There have been some parts though that, either for the complexity to include them to the model or because of the fact of being outside the scope of the project have not been incorporated. These are mostly of the nacelle:

- Spikes on the inlet side of the motors
- Some frames on the nacelles
- Exhaust nozzles

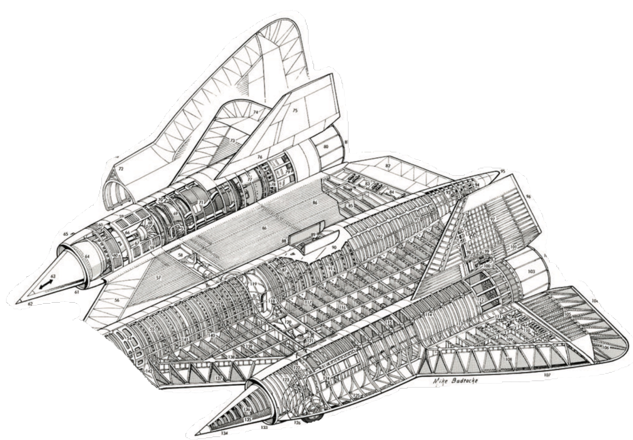


Figure 5.12: *Aft of the SR-71* [1]

Studying this part, it has been seen that fuselage, wing structure and nacelles are attached, and they finally form a unit. This has been taken into account in order to design it through the CAD Software so that this attachments are one simple unit, in the majority of cases. This simplifies the process of construction of the model and the inconveniences that would imply too many unions of pieces.

Following a similar pattern to previous stages, the aft fuselage combines a circular frame (rings), and the spars or ribs that form the wing structure all along to the nacelles. It has been divided in these parts of working:

- **Front**: from the forward/centre fuselage joint to the landing gear bay.
- **Aft**: from the landing gear bay to the end of the fuselage. These considerations have to be made:
  - In the first place, the fuselage is regular. Then the frames start to decrease in size to get to the most extreme section of the airplane.
  - This part, as has been introduced in the *Parts* Section, features not only the inner wing (structure between fuselage and nacelles), but also the outer wing structure. This is attached to the nacelles. Actually, this would be a movable part in order to access the engines. This can be seen on Image 5.12, right side of the plane.
- **Control surfaces**: Elevons (on each side and center).
- **Fins**: Also constitutes a control surface, specifically the rudder.

One of the parts that requires more attention, and that has been more different with the concepts that are familiar are the leading edges. These are composed with what is called RAM wedges. Instead of using regular ribs, it features these segments, disposed to form a triangular shape and the leading edge for the wing. This arrangement is also used for the trailing edges of the elevon control surfaces (both lateral and center).

5.3.1 Front

To begin, the central part of the first frame has to be of the same dimensions and shape of the last one of the front fuselage. Then, the two pieces can be united. This join must be very firm, because it is in this point where two big parts (actually is half the plane) are assembled together. The frames that unite the two parts in real life have a difficult shape to design if it is taken into account that they need to be cut later in a laser machine, and the design is 2D. They are very wide frames to properly be cut to create the model, and there's the requirement that the material must have a low thickness.

Then, it has to be established the pattern that the airframe follows. As it has been mentioned, it follows the pattern of combining what may be called, principal frames, and between them, two rings, that give strength to the airframe. These principal frames have attached the spar panels to form the inner wing. Also, every four principal frames, there's an arched beam that provides robustness.

When it comes to this principal frames, they are distributed:

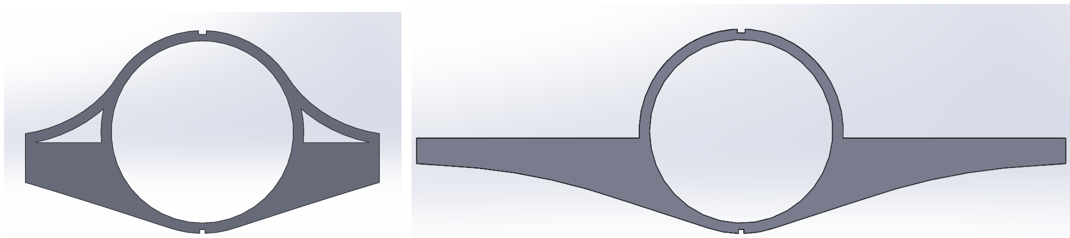
- 5 frames, that get bigger
- 6 frames, attached with part of the nozzle structure.

It has been incorporated an upper and lower longeron in order to join all the frames, both principal and ring frames. As can be determined from the cutaway of the structure, the fuselage is regular in this part, and the wing spars get bigger longitudinally, so that it forms a delta shape. Also, they get wider in order to accommodate the beams that unite the structure, that form the airfoil of the wing. The leading edge of the wing incorporates the mentioned RAM segments, forming a triangular structure, attached to a diagonal beam.

The nacelle structure has attached an outer wing chine structure. It follows the shape of all chines of the Blackbird, that gives its characteristic and recognisable shape.

In order to begin, the first frame has to be of the same dimensions and shape of the last one of the front fuselage. Then, the two pieces can be united. This join must be very firm, because it is in this point where two big parts (actually is half the plane) are assembled together. The frames that unite the two parts in real life have a difficult shape to design if it is taken into account that they need to be cut later in a laser machine, and the design is 2D. They are very wide frames to properly be cut to create the model, and there's the requirement that the material must have a low thickness.

Following a similar method to previous stages, it has been used the operation *Loft* to know what are the dimensions that must have the frames so that it follows the most realistic way the airframe of the SR-71. As it has been said, all components of the fuselage has the same exterior dimensions, although the hole made inside has differences. The rings have a 3mm offset with the exterior circle, and those that compound the principal frames have a 4mm offset. Then, for this part, the differences come on the spars. Figure 5.13 shows the difference between the first frame and the last.



((a)) First frame ((b)) Last frame

Figure 5.13: Frame comparison of the frontal section of the aft part

These frames are for the most frontal part of this airplane, where the RAM leading edge is attached too. Then, the ribs start incorporating the nacelle, as shown in Image 5.14. Highlight also the lateral chines attached.

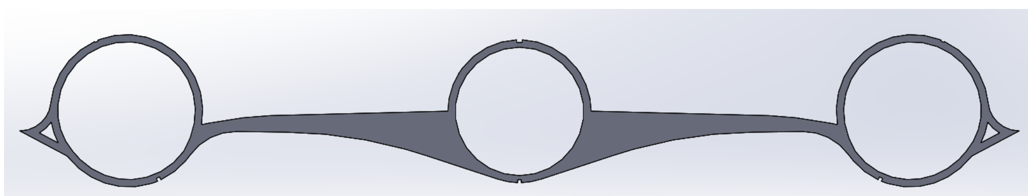


Figure 5.14: *Rib incorporating nacelle components*

Figure 5.15 shows the operation done to create one of the frames. Note that they are actually 3 circles, with tangent lines and arches that define the characteristic shape of the Blackbird, with the measures taken and scaled.

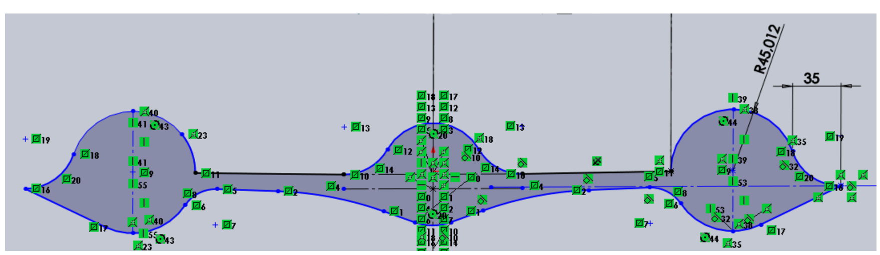


Figure 5.15: *Operation to create one of the frames*

Looking at Figure 5.14, one can note the insertions on the exterior to be linked with the longerons. These are situated at a certain angle anticlockwise from the vertical line of symmetry of the circumference. Thy go all along the length of the engines. It has been taking into account that that nacelles are not completely horizontal and they have actually an angle of approximately 5º. This collocation regards not only the plans, but also it would be the place were the hinge is placed in the real plane to access the J58 engines.

The edges of this part are composed by the RAM segments mentioned. All pieces have been designed to be attached to two beams on each side, and united with the principal frames. One of this beams, the one that is in contact with the frames has holes in order to increase the strength of the union. They change its shape with the length of the diagonal beams.

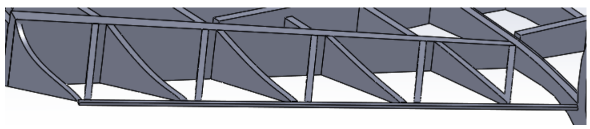


Figure 5.16: *Leading edge of the section*

This part has been designed using its characteristic of being triangular seen from a top view. It has been generated a solid after using *Loft* between two profiles, imposing the leading edge shape that the SR-71 has, which is very thin, typical from hypersonic aircrafts. Figure 5.16 shows a closer look to this part of the 3D CAD model created in *Solidworks*.

Figure 5.17: *Photograph taking a closer look to the leading edge of the frontal part of the wing of the Blackbird*[14]

In Figure 5.18, it can be seen the operation made to create this part, in a top view and showing the triangular shapes.

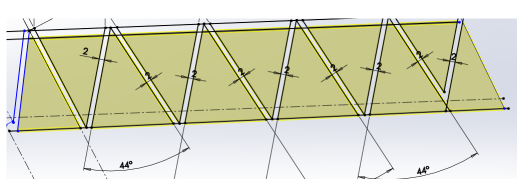


Figure 5.18: *Sketch made for the RAM segments*

Logically, in order to make the union of all parts of the airframe, it has been needed to use bigger beams to support. Thinking on the later model that has to be constructed, it has the orifices made so that they fit in with the thickness of the rest of the wing structure. The objective is that they are attached with the most amount of pressure possible, rather than glued together, so the union can be stronger when the model has to be assembled. Figure 5.19 shows these two beams incorporated.

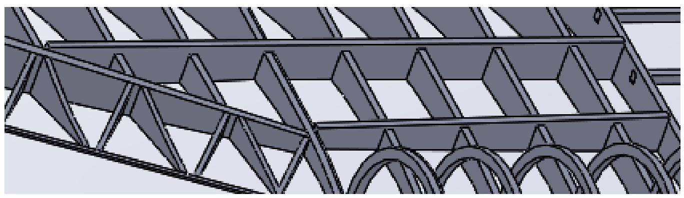


Figure 5.19: *Principal beams of support of the aft's frontal airframe of the SR-71 model*

The nacelle, doesn't follow, for this part, the same configuration of two rings between each principal component of the structure. Nevertheless, as it will be regarded later, for the next parts it will be incorporated. This has been the most feasible and accurate way that has been found to create the model, regarding this with a compromised point of view. Figure 5.20 shows this part, with the longerons already mentioned incorporated to secure the structure.

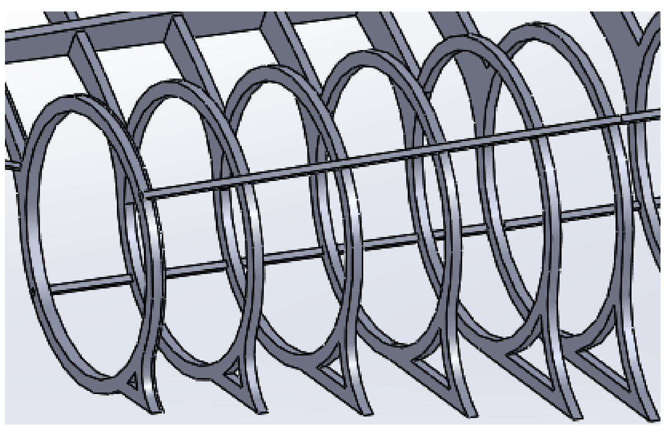
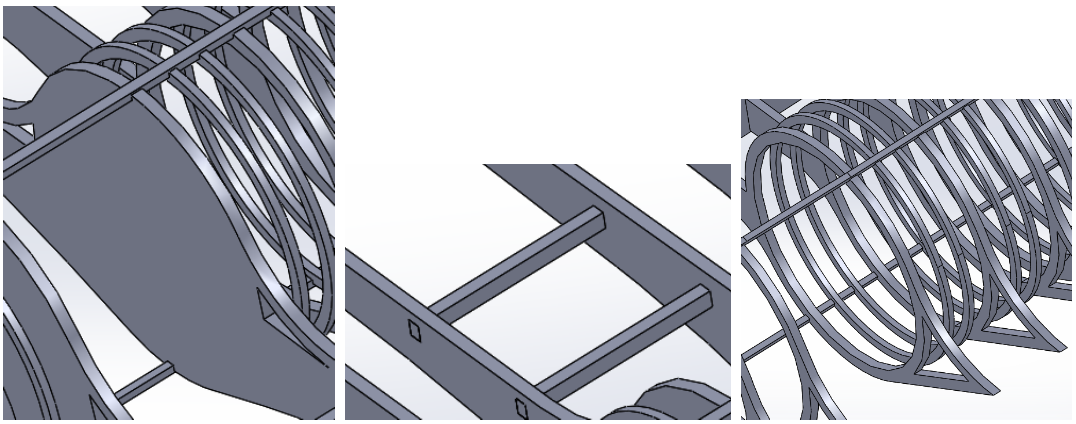


Figure 5.20: *Structure of the frontal nacelle structure, featuring the longerons*

5.3.2 Aft

This section begins with the same rib used in the final one of the front. These two must have a proper union, that has been chosen to be, taken into account the cutaways. Then, the elements that help on this are:

- Two fuselage longerons (up and down). Figure 5.21(a)
- 4 beams (2 at each side). Figure 5.21(b)
- 4 longerons on the nacelles (2 at each side). Figure 5.21(c)



((a)) Fuselage longerons ((b)) Union beams ((c)) Nacelle longerons

Figure 5.21: *Elements helping to unite front and aft parts, in the landing gear bay*

Then, with the purpose of designing the different frames of this part, it has been followed a similar procedure as the rest of the aircraft. That is, creating principal frames, were the structure has some particularities, and then adding the necessary ribs between them. These particularities are located in:

- In the fuselage, in the line of symmetry, were it begins to decrease in size.
- In the laterals, were the line defining the outer wing begins
- The frame supporting the lateral elevons
- The frame supporting the central elevons
- The nacelles have an inhomogeneous pattern

The first frame hasn't got a hole in the middle, because the fuel tank of the fuselage is partitioned in two parts, in this case. Image 4.4, shown in *Structure and Parts* Chapter represents this aspect. Then, the next ones, as they have to carry the fuel tanks, they feature the mentioned perforations. Specifically, they are the ones named Tank 4 and 5.

The first particularity to mention is the union of the chines/outerwing, shown in Image 5.22. As can be seen, here is the last place were the characteristic chine structure is incorporated, and the outer wing components are created.

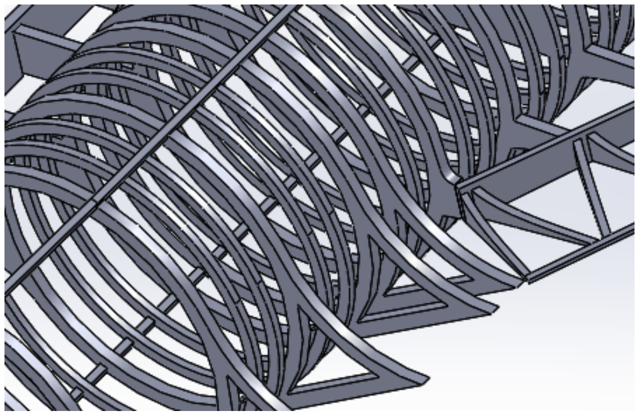


Figure 5.22: *Union of the outer wing and chine structure*

Here, then, it starts the structure of the outer wing. It has been designed to be attached to the nacelles, following the plans and cutaways that have been found. In order to find the dimensions of the outer wings, it has been created a plane, that includes the line that defines the front leading edge and perpendicular to the horizontal plane. Doing this, it can be known where the outer wings end, and it can be defined the delta wing shape that all the Lockheed SR-71 defines, seen from a top view.

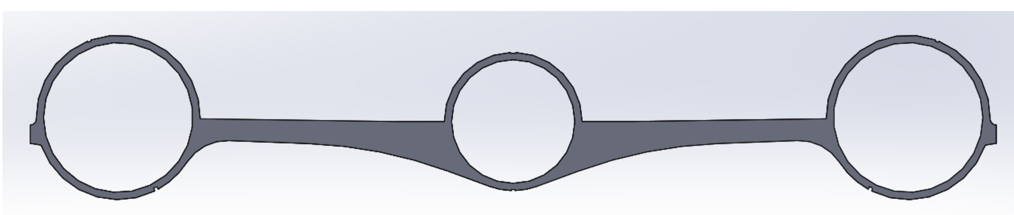


Figure 5.23: *First frame of this section, incorporating the extension to accommodate the beam that will support the RAM segments of the outer wing leading edge*

Then, Figure 5.24 shows the second frame of the section. Note the arched support elements in the center and the enlargement of the wing part compared to Figure 5.23.

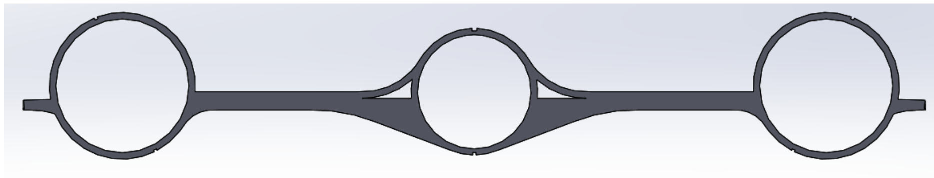


Figure 5.24: *Second frame of this section, incorporating part of the wing structure*

It must be mentioned here that, in contrast with the frontal part of this aft section of the Blackbird, the support elements are incorporated every 3 frames. One example of this kind would be the one shown in Figure 5.23.

Then, when it comes to the fuselage, it starts decreasing in size, approximately near the two thirds of the length of the aft of the SR-71. It decreases in a pretty reasonable constant curve (seen from a lateral view) until it reaches the end of the aircraft. It must be mentioned that the most external part, that is a cone, hasn't been implemented as in reality this would be incorporated in the airframe as a unit. So, this decision has been taken considering the materials and procedures that are available to do this project, and that a 3D printing or some similar method would be necessary.

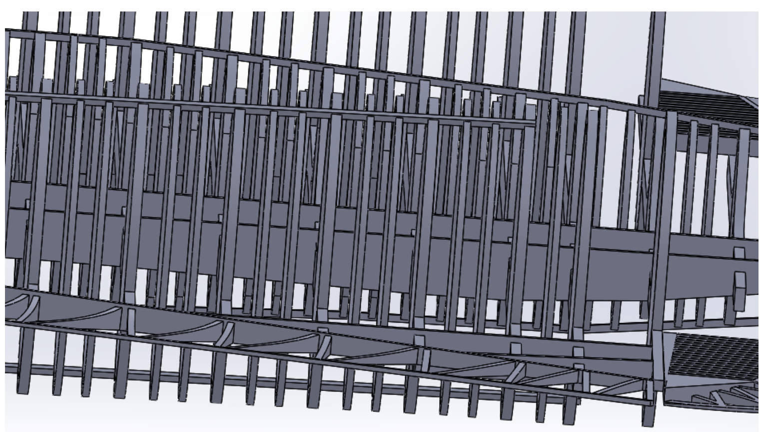


Figure 5.25: *Capture of the 3D Solidworks CAD model. Note the top fuselage drop line*

Another piece to take into account is the frame supporting the outboard elevons. It has the particularity that, between this one and the anterior, there's more space than others. That's because there won't be placed any intermediate nacelle rings. This space is designed, in the real plane, to function as a cooling part for the engines. As it has been seen and explained, these aft parts of the nacelles are the ones that have the most critical when it comes to high temperatures. Also, it is the last frame that contains the outboard wing structure.

It can be noted that, here, there's a lot of difference between the circumference that defines the fuselage and the nacelle structure, as the fuselage gets smaller as it gets to the back of the aircraft.

Then, it has been also taken into account the last frame, that acts as a support for the central elevons. It has the particularity, that seen from the top, the laterals are not straight, because the control surfaces are positioned sideways and outwards.

The last cone of the aircraft hasn't been designed for the reasons established at the beginning of this section.

Finally, the most external part of the outboard wings, similarly to the front, it follows the same pattern: Segments, positioned in a triangular shape, that form the leading edge.

Table 5.2 shows as a summary, the number of pieces:

Type of frame	Number	Thickness
Principal frame	16	3 mm
Fuselage rings	27	2 mm
Nacelle rings	40	2 mm

Table 5.2: Number of pieces summary for the aft part

5.4 Control surfaces

In this section, it will be explained the design of the control surfaces. These are:

- Outboard elevons
- Inboard elevons
- Fins

Both elevons have been designed to be a made of a single piece. This has been done for several reasons. First, it simplifies the construction. As it will be seen, they is composed by a number of pieces, and the union of them may be incorrect or imprecise. Also, this implies that, being a single piece, it will be more solid and the shape derived is more consistent with the reality. It does have, though, a drawback. This is that the lateral shape, that forms a leading edge can't be obtained directly after being cut on the laser machine because it only cuts in 2D (top view).

They will be explained differentiating the outboard and inboard ones.

5.4.1 Inboard elevons

They are formed by two well differentiated parts. First, it has been designed a set of beams, specifically 11, and next to them, at each eternal side, there's another 2 to finish this part. They have been designed two elements to be connected, one side with the support frame already explained, and the other side with the rest of the elevon. Then, this last is attached to the segments that form triangles.

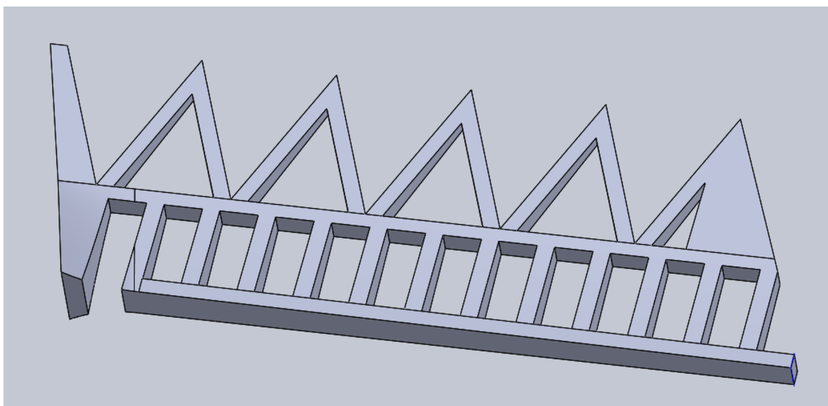


Figure 5.26: *Inboard elevon*

5.4.2 Outboard elevons

These have a more complex design than the inboard elevons, but actually follow a similar pattern. First, it has been designed the set of beams, in this case 16; and then, the triangles. Then, it has been designed an arch, that has attached three more triangular shapes. Also, in order to unite these arched section and the beams, it is designed a solid triangular shape, all this following the accessible plans.

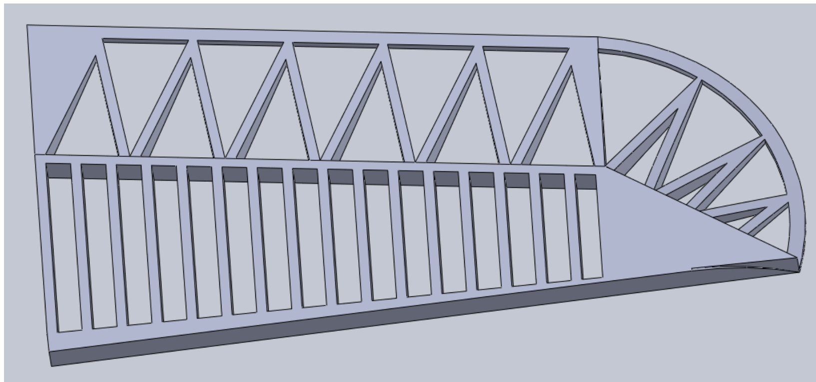


Figure 5.27: *Outboard elevon*

5.5 Fins

The fins are composed, basically, by a wing structure with ribs and spars. As it can be seen on Figure 5.28 the first section is composed by ribs, combined with vertical spars that unite them all. It has also been designed a space approximately in the middle for the mechanisms that actuate the rudders. This is extended vertically in order to fit all these devices.

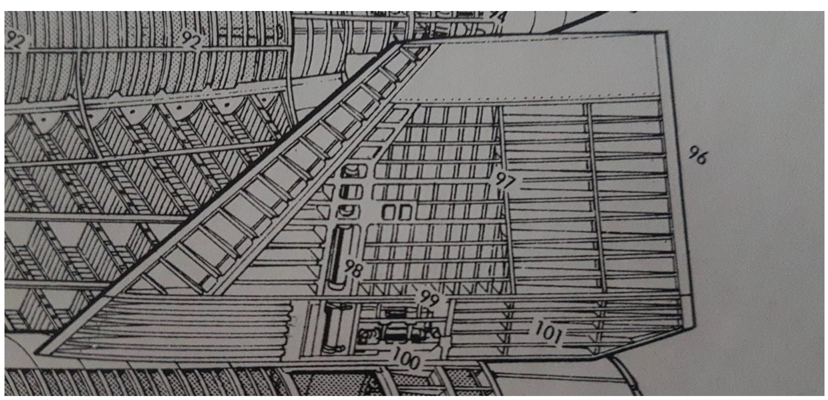


Figure 5.28: *Structure of the fin, extracted from Mike Badrocke's cutaway*[1]

Then, it has been needed to know the shape of the ribs. They are symmetrical airfoils (important so that there isn't lateral instability). Through the top view, it can be noted that they have a shape very similar to an ellipse, and that is what it has been approximated to. Figure 5.29 shows the operation that has been made to design the shape of the ribs that compose the fin, with its dimensions. The one shown in the picture is the lowest one, that is attached to the nacelles.

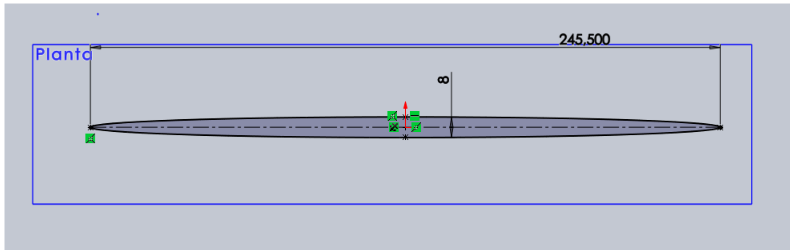


Figure 5.29: *Operation that shows the shape of the ribs*

The other ribs have been created using the operation *Loft* between two profiles, so that it is easily known the dimensions that have the intermediate elements. Figure 5.30 shows this operation.

The first and final rib if this first section are complete airfoils but the other are partitioned, and attached to spars.

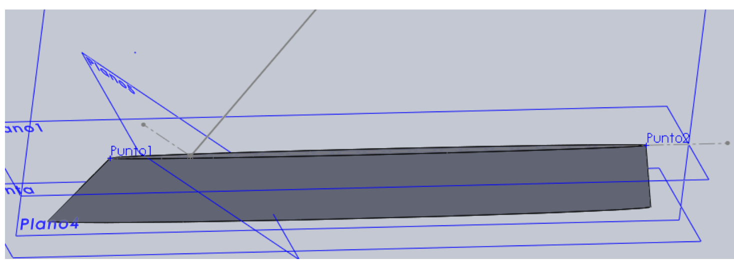


Figure 5.30: *Loft operation on the fin*

It hasn't been found plans of the rudder itself, but attached to the aircraft. It must be mentioned, though, that it is not positioned vertically. It is actually inclined inwards in a 15^o angle. Then, in order to take some measures, it has been needed to apply trigonometry.

The upper part of the fins is partitioned in 3 parts, as can be seen in Figure 5.28:

- Left: Partitioned airfoils
- Center: Grid structure
- Right: Partitioned airfoils

For the left section, it has been used the Operation *Loft* and it has been cut the necessary elements. They are attached to the diagonal beam. This last will also act as a base for the leading edge segments of the fin. Then, there has been left an space that would fit the mechanisms of the rudder.

The grid structure (Figure 5.31) has been designed to be a single piece. At the right ends, it has some gaps so that the right partitioned airfoils have a better point of support.

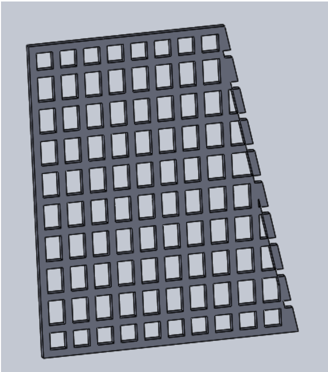


Figure 5.31: *Grid structure*

Then, the ends of the airfoils are attached to the grid. Figure 5.30 shows the full structure of the fin.

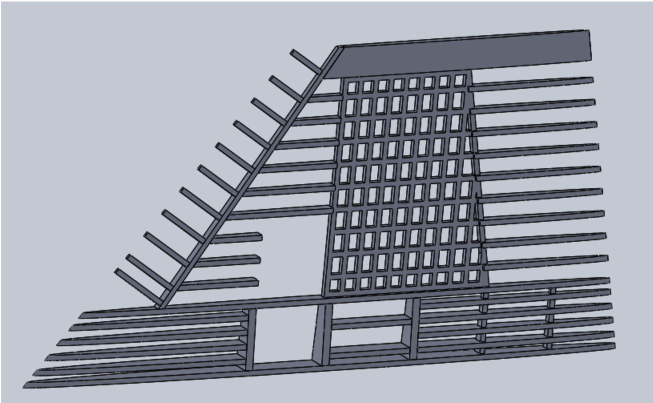


Figure 5.32: *Full structure of the fin*

Then, the total number of pieces, for each fin are:

- 2 full ribs
- 28 partitioned ribs
- 5 spars (trapezoidal, to follow the shape)
- 1 diagonal spar

5.6 Final result

Figures in this section will show the final 3D CAD result of the Lockheed SR-71 structure, through different views.

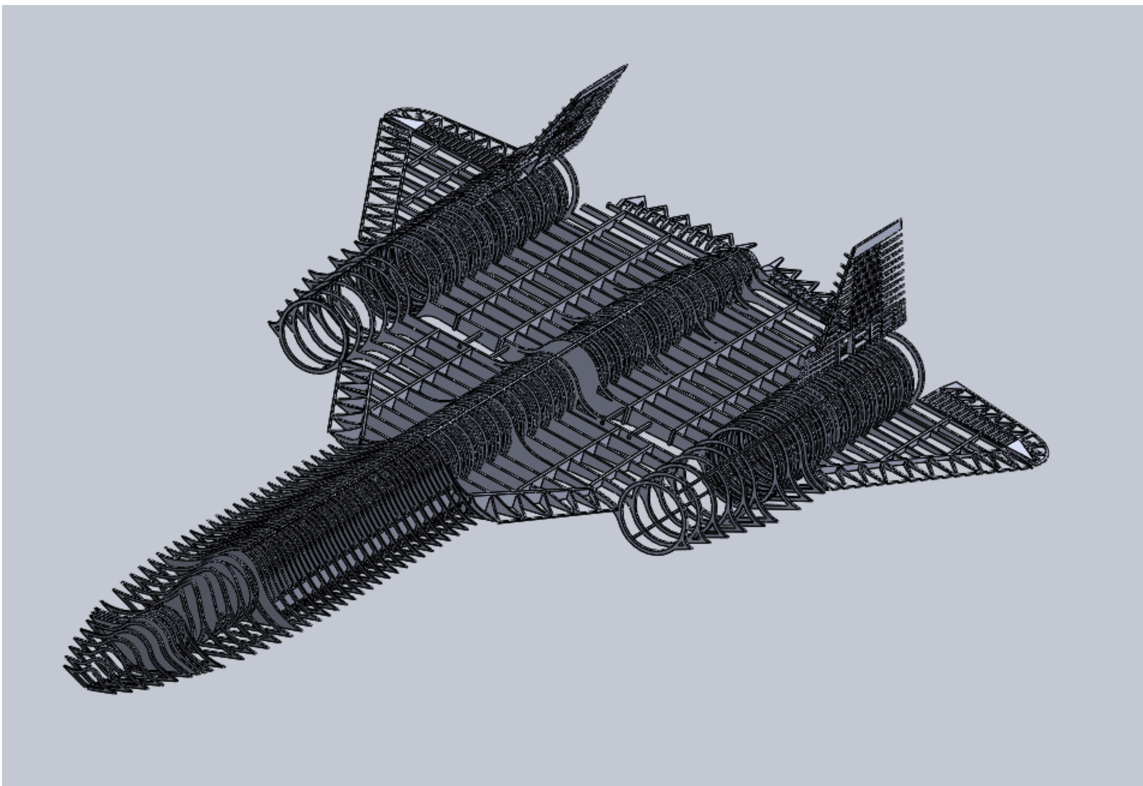


Figure 5.33: *Full 3D CAD structure of the Lockheed SR-71*

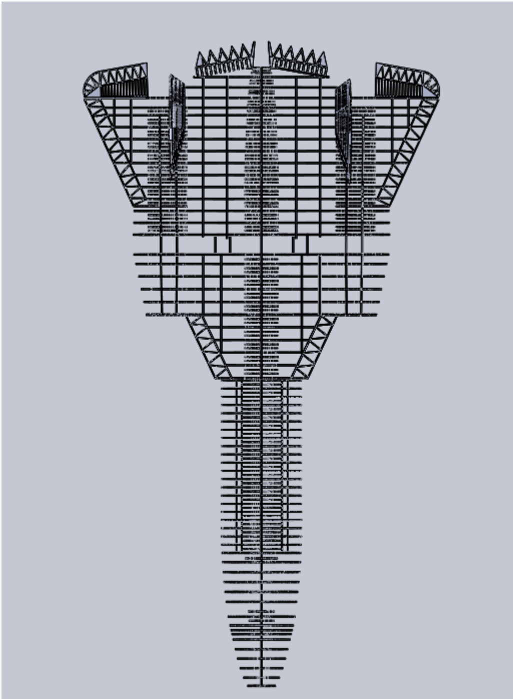


Figure 5.34: *Full 3D CAD structure of the Lockheed SR-71 (top view)*

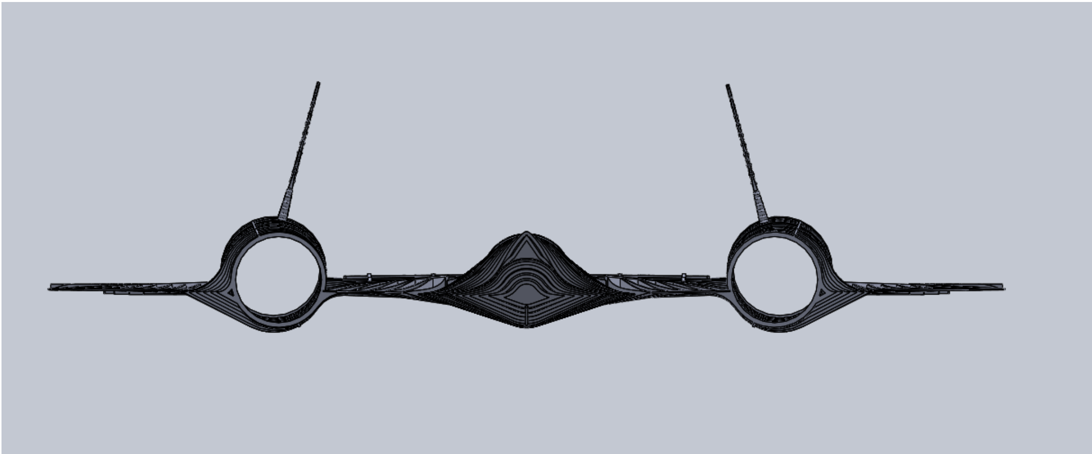


Figure 5.35: *Full 3D CAD structure of the Lockheed SR-71 (front)*

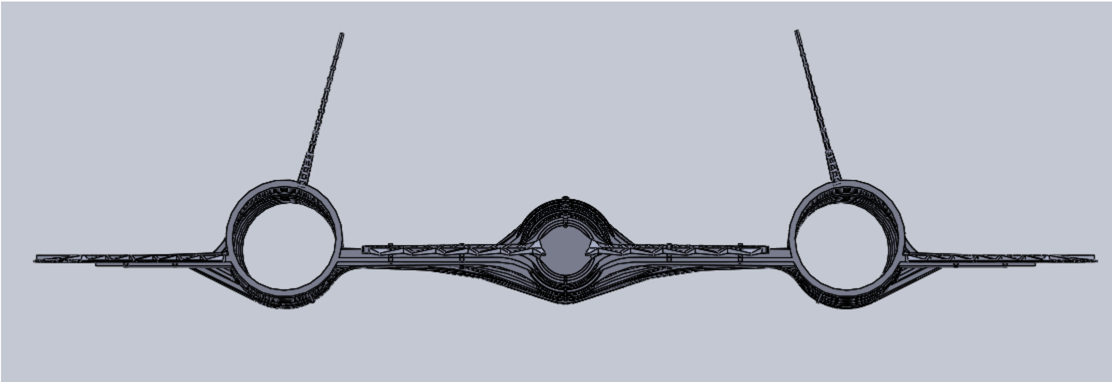


Figure 5.36: *Full 3D CAD structure of the Lockheed SR-71 (back)*

5.6.1 Final dimensions

Figure 5.37 provides the final dimensions for the Lockheed SR-71 model created in this thesis. This is actually part of the *DRAWINGS* documents attached with the rest of files required with the delivery of the thesis.

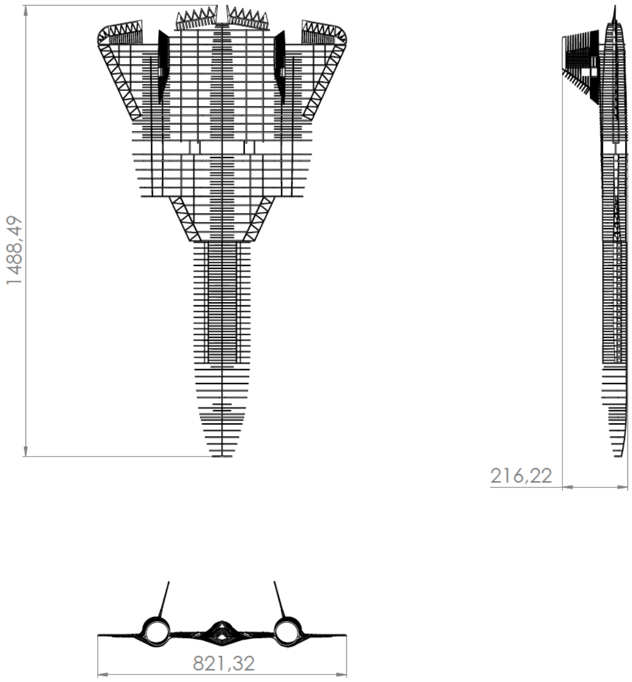


Figure 5.37: *Final dimensions of the model*

Chapter 6

Construction of the model

This chapter explains the process of constructing the model after having created the 3D model in *Solidworks*.

It has been divided in different tasks:

- Division of the pieces
- Plans collection
- Materials collection
- Cutting of the pieces
- Construction

6.1 Preliminaries

As it has been explained, all the plane has been divided in two parts, front and aft, and then they have been united. Logically, every part has multiple sub-parts in order to assemble the total model. All of these, that have been mentioned in *CAD design* section have to be obtained from the big two parts and properly distributed.

Then, each piece, using *Solidworks* derives in a drawing. The laser cutting company that has been contacted gave the instructions of how the archives should be sent. These were:

- **Archive type**: .dwg
- **Dimensions**: the pieces have been sent in A0 plans. This has been done because the plane of working area of the machine used by the company had similar dimensions of an A0.

- **Distribution**: The pieces have been distributed on their thickness (2 mm or 3 mm). Also, using the maximum space of the working area so that the material used is the minimum.

When it comes to the materials, after having decided of making the model of wood, because of the difficulty that would have working with a different material like metal or plastic, the wood genre had to be determined. Initially, the intention was to use balsa wood, but was eventually discarded following the recommendations given by the company, because some small pieces may have been broken and lost after cutting them due to the fragility of this material. Then, the options were:

- Birch
- Beech
- Sapelly
- Linden
- DM

The decision was to use Linden, due to its compromise between price and strength. These have been used for the 2 mm pieces, and for the 3 mm it has been used DM. This has been done for two reasons. First, the availability of the 3 mm of thickness Linden wood was limited and the price was high. Actually, due to the big pieces, a lot of 3 mm has been needed and the cost would have been too high. DM has been a very good option, because the cutting company itself could provide this material and it has a very good resistance and its price is low. It has to be mentioned that the model couldn't be all constructed in DM because the minimum available thickness was 2.5 mm.

So, the 2 mm material has been needed to be bought and provided to the cutting company. It was obtained in wooden boards of dimensions 100x25 cm.

After having sent all the plans in the correct format, the material was brought to the company workshop. Figure 6.1 shows the received pieces in the workshop.

6.2 Construction

In order to begin with this important task for this project the pieces have to be distributed and differentiated. Even though the pieces were given in distribution bags, these actually didn't correspond to the different parts.

Figure 6.1: *Pieces cut in the workshop*

These were distributed taking into account their position. Also, as the model has symmetries, many parts are repeated so it has been important to make pairs and groups, see an example in Figure 6.2.

Figure 6.2: *Organization of pieces*

The construction of the model has begun with the frontal part of the aircraft, starting with the lower beam. The different frames have been attached to it, taking into account the model created on the program for the position and measures. This part has the particularity that the rib is not straight, so correctly positioning the frames has been a challenge. Although this aspect, this first part has been a good way to get acquainted with the process of construction, and to check the cutting of the pieces, especially the unions between beams and frames. In order to join the parts it has been used *Loctite*, for the capacity of obtaining a very strong union and fast, so that the process is accelerated. As it will be explained, later, this part has had a modification of the initial plan.

This frontal part finalizes when the 3 mm DM pieces are no longer used (for the first half of the airplane). Here, it begins the 2 mm Linden, with the not regular and regular part (circular frames) already explained in *CAD design* Chapter. Here, it has been used a similar method. It has been attached the frames to the lower beam (it's the same one than the frontal part). Nevertheless, this part has the particularity of having two beams at each side, that need to be fitted and inserted through slots. These are many, so it has been also a challenge. It must be mentioned that in the first instance, they were glued to the beam the frames that have attached the lateral chines, and then between each one the frames with no fairings.

Then, after having united the lower beam, and the lateral ones, the top beam has to be attached. This gives an extra stability and strength to the structure, and helps aligning all the pieces. Here, when it comes to the gluing, it has been used for every union *Loctite* excepting the union of the beam closer to the line of symmetry, where it has been used *white glue*, as it is cheaper and strong, but requires a longer period of time to act. Nevertheless, as the pieces were already united because of the action of other frames and beams, a glue of fast drying wasn't needed.

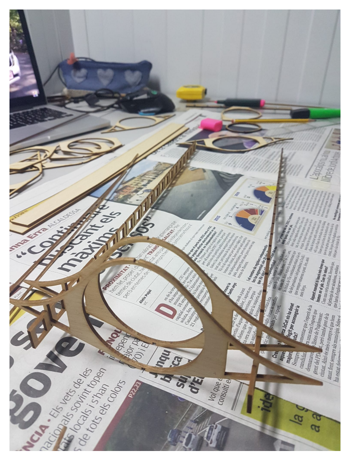


Figure 6.3: *2mm Linden part start*

Strength checking of the structure has been made through all the process in order to ensure a proper final result. When the frontal part had the requirements planned earlier, before starting the construction phase, the model was continued to be created, that is the aft of the aircraft.

The aft multi-spar and multi-rib structure of the Blackbird has been begun with the correct attachment of the lower fuselage beam and the first frame. Then, considering the distances between frames, consulting the 3D CAD model, they were also attached. Similarly to the procedure made at the beginning, the principal frames were attached and then the intermediate rings (in this case two at each space). It has been needed, for this part, an even better alignment of all the pieces, as the number of intermediate pieces is doubled. In order to differentiate the rings (there are rings for the nacelles and the fuselage), and the dimensions are similar, it has been crucial the inserts made, because for the fuselage rings the top one is 3 mm and the lower is 2 mm.

Figure 6.5: *Starting on the construction of the aft structure*

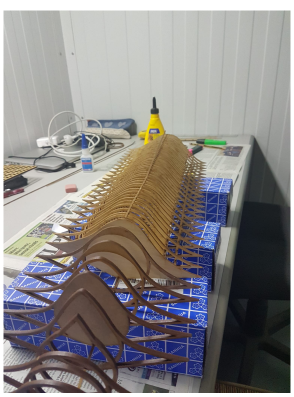


Figure 6.4: *2mm Linden part start*

Then, the two spar/beams that unite the structure (mounted in the inner wing) are incorporated, having been properly aligned. These are crucial elements for the strength and formation of all the structure.

After this initial part, there comes a critical section for the full structure of the model. That is the area were the landing gear of the aircraft is supposed to be mounted in. As it has been known through the plans, the big spar/beams that support the structure are not part of this area, said in other words, they are partitioned between two parts. The union has been entrusted to the lower and upper fuselage beams, nacelle beams and the two elements at each side. As it will be explained later, these two elements were initially designed to be made of DM wood, but was redesigned. The final union has been a very good result.

For the back it has been followed an almost identical procedure, but the descending pattern of the fuselage has been a difficulty comparing it to what would be a regular structure. It has been very important the correct classification and sorting of the pieces. This has been done, basically, comparing the size of each one so that the scaled pattern is created.

Now the external parts of the outer wings will be explained. These have represented one of the most painstaking work of the construction. Nevertheless, front and aft parts follow a similar pattern and procedure, so, after having created the first one, it has been easier to make the construction more efficient, or obtaining a good result with less work time.

Every segment has been needed to be modified in order to be disposed in the way they should be. As the laser cutting machine didn't provide trimming on the Z direction, it has been needed to sand some pieces in order to obtain the triangular shape that they compose. Also, taking into account the inclination due to the delta wing that the SR-71 features. It was mandatory to be very cautious with the correct disposition of this airfoil segments, as the shape of it is not very different (upper and lower camber) because it's almost symmetrical, and the pieces are considerably small.

Then, every frame has been fixed to the long beams that cover all the wing. If they were not disposed the way they were designed to, the shape of the wing is not constructed properly. This, applied to a real aircraft, could cause many problems of lift or drag, added to problems of stability both aerodynamic and structural. So, it has been very important to work carefully and following the design made.

The fin structure has also been a major challenge in the project due to the number of pieces that it has, and the little dimensions of it. This made the process of identifying the different parts complicated. Figure 6.6 shows this process. Each piece was numbered to ease the work.

Figure 6.6: *Fin pieces organization*

In order to build this part of the model, it has been initiated by assembling the partitioned airfoils to the vertical beams and attaching them to the complete airfoils (up and down). It has been checked that the pieces create a descending pattern, characteristic for the fins of the SR-71 Blackbird.

Next, the grid structure has been united to the upper airfoil and glued to the grid, the partitioned airfoils on the right. They fit in the insertions of the grid, already designed in the program.

Finally, the beam, where there have been attached small partitioned airfoils that create the leading edge of the fins is added, taking into account the diagonal disposition that it has. It has been needed to perform sanding, similarly to other pieces already explained, so that the desired result is obtained.

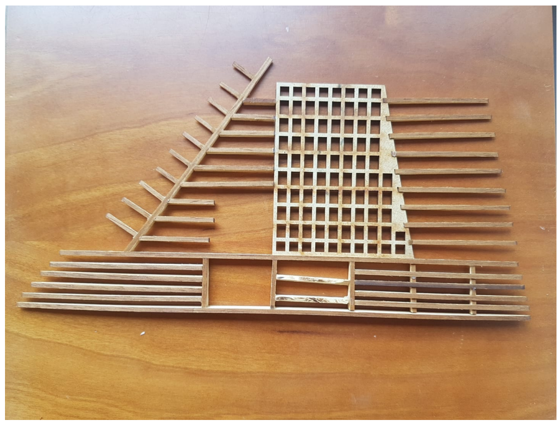


Figure 6.7: *Finished fin structure*

6.3 Modifications and improvements on the construction phase

The construction phase has carried two major modifications of the design, as it has been mentioned earlier, in order to obtain a correct result. It must be said that these have not led to an incorrect nor misleading representation of the real structure of the aircraft, but they have been crucial to the construction of the model.

6.3.1 Nose section

The nose section has undergone an improvement of the initial design made via *Solidworks*. This has been the addition of a superior beam and two lateral ones.

When it comes to the superior beam, it is a stainless steel wire that has been manipulated using pliers. Doing this, it fits the irregular dimensions of the frames. It is attached, on the aft side to the regular part of the front fuselage. Some perforations have been performed to some frames to have a better subjection. The wire is reclined to the rest of the frames and glued.

Figure 6.8: *Interior part of a connection strip*

The wire is partitioned between two parts. This is the cabin section and the nose section (good representation of the reality as the nose section is detachable). These two are united using the interior part of a connection strip (the plastic has been removed), that features two screws to secure the union (See Figure 6.8). The wire used for the nose section has needed a lot more of modification with the pliers help, as this part has an even more pronounced shape.

Figure 6.9: *Union of the wires using a connection strip*

On the other hand, the two lateral beams help that the structure is more strong to circular movements on the vertical axis. These have been made of Linden wood, of 2 mm of thickness, and they feature the curvature that the chines of the SR-71 draw. This can be seen in the Figures of the section *Final model result.*

6.3.2 Landing gear area

As it has been mentioned earlier, the union of the two parts divided by the area left for the landing gear has experienced an improvement of the design. Instead of using 3 mm DM wood, it has been used a 2 mm stainless steel threaded rod (Figure 6.10), that takes advantage of the holes made on the frames . Logically, in order to attach it to the frames it has been employed washers and nuts.

It must be mentioned that the threaded rod was bought as a very long piece that was needed to be cut with a radial saw, and the extremes of the cut parts sanded so that the nuts could pass through.

The result of this modification has been very satisfactory, taking into account not only the strength of the resultant structure, but also the visual aspect and the correct representation of reality.

Figure 6.10: *Union of frames in the landing gear area*

6.4 Final result

The construction of the plane has ended with the addition to the rest of the airframe of the control surface elements (fins and elevons). Also, the two principal parts of the plane (front and aft) are attached.

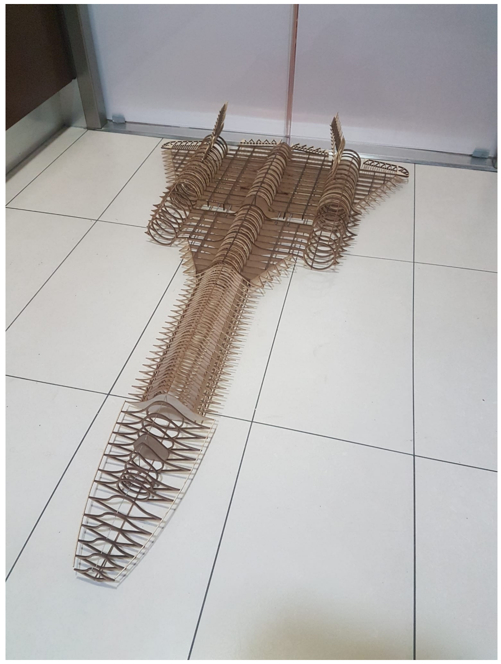


Figure 6.11: *Final result of the Lockheed SR-71 model*

Figure 6.12: *Final result of the Lockheed SR-71 model (top/rear view)*

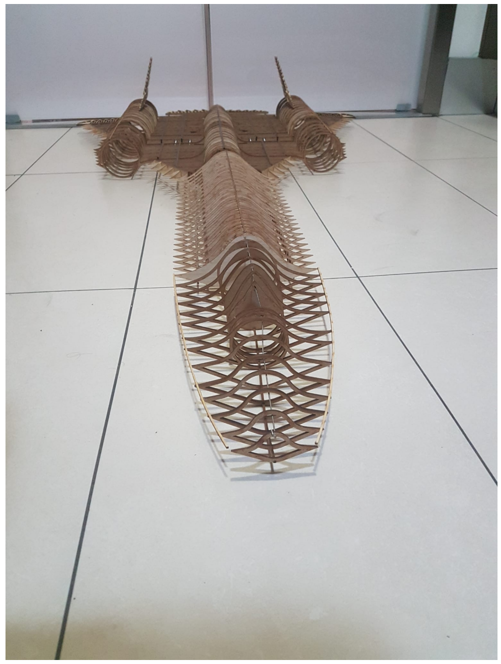


Figure 6.13: *Final result of the Lockheed SR-71 model (frontal view)*

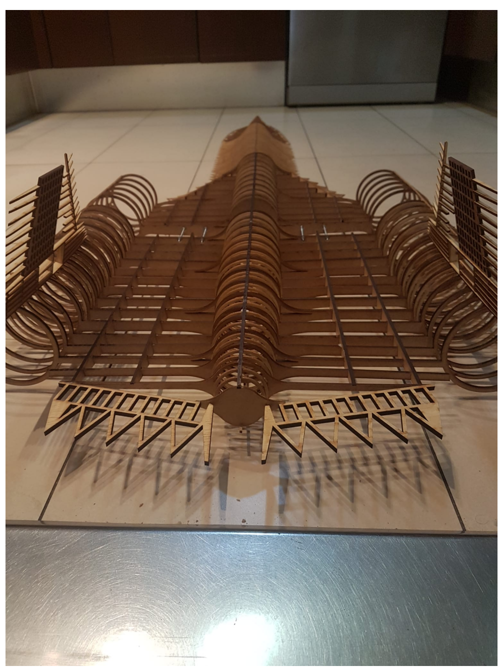


Figure 6.14: *Final result of the Lockheed SR-71 model (rear view)*

Figure 6.15: *Final result of the Lockheed SR-71 model. Closer look to the fins and outer wing structure*

Chapter 7

Lessons learned and conclusions

Through the development of this thesis it has been a very good way of learning the structure of such an iconic aircraft like the Lockheed SR-71. Thanks to the fact that every piece has been needed to be designed and produced, the process of studying and understanding the airframe has been both more interesting and fulfilling on the knowledge of aircraft design construction. It has also been a convenient manner to get to know a different kind of airplane structure, that contrasts with the classical commercial aircraft or light plane that has been seen through the degree.

Furthermore, it has represented an important aid when it comes to the proficiency on the use of the CAD software utilized for this thesis, that is *Solidworks*. In addition, it has been worked on the process of developing plans, taking into account the rules that exist when an engineer has the task of producing drawings with measures of some technological device.

It has been very important the competence of organization. Not only to follow the schedule and the timelines defined to complete the final degree thesis, but also for all the pieces designed through the development of the airplane model. It must be taken into account the number of parts of it: without a proper arrangement it may have been an important problem in order to finish the study.

Then, it has been needed to learn some commands and operations on the CAD software in order to create the 3D design, but it has been a great aid the course done the in the first year of the degree, *Expressió gràfica*, where *Solidworks* was introduced, in addition to the normalization of plans.

Some problems and difficulties have come along in this project. First, due to the high degree if secrecy on the information of the Blackbird planes, it was pretty difficult to find some data to begin and continue with the project. Also, some aspects related to the aircraft were needed to be compared or contrasted because they were either from not very reliable sources or SR-71 fan pages were enthusiasts publish data. It must be mentioned also, that the COVID-19 crisis in which this thesis has been worked on has affected some aspects of the development of the project. It has been encountered the issue of contacting companies to cut the material in order to build the scale model. Those contacted at the beginning either did not respond or they closed during lockdown. Then, there were some problems when it comes to the format for the plans that the workshop may ask so that they could be cut, and this caused issues and changes on the schedule and the model has been begun to be constructed later than expected initially. Nevertheless, this task has been finally accomplished thanks to the correct sending of the plans.

Finally, through the model constructed, that reflects all the work done through these months, it can be considered that the result is very satisfactory, not only visually but also structurally. The model complies the strength and robustness required for a real aircraft.

In conclusion, it must be declared the satisfaction when finalizing this thesis. It has been pleasing to see the model being created from a scratch on the CAD software. This, with no doubt, reflects one of the important tasks that an engineer may have to complete during its professional career.

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